PB90-109473

Watershed Surveys to Support an Assessment of the Regional Effects of Acidic Deposition on Surface Water Chemistry

Oak Ridge National Lab., TN

Prepared for:

Department of Energy, Washington, DC

1989

U.S. Department of Commerce
National Technical Information Service
NTIS

ERL-COR- 854JAP

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before complet

1. REPORT NO.	2.	3.
EPA/600/J-89/107		PB90-108473

4. TITLE AND SUBTITLE
Watershed surveys to support an assessment of the regional effects of acidic deposition on surface water chemistry

5. REPORT DATE

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
J. Lee,[1] R. Church,[1] D. Lammers,[2] L. Liegel,[2] M. J,[3] D. Coffey,[3] R. Holdren,[3] D. Stevens,[4] R. Turner,[5] and L. Blume[6]

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
[1]USEPA, Corvallis, OR, [2]USDA, FS, Corvallis, OR, [3]NSI Technology Services Corp., [4]Eastern Or. St. Col., LaGrande, [5]ORNL, TN, [6]USEPA, Las Vegas, NV

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
US Environmental Protection Agency
Environmental Research Laboratory
200 SW 35th Street
Corvallis, OR 97333

13. TYPE OF REPORT AND PERIOD COVERED

14. SPONSORING AGENCY CODE
EPA/600/2

15. SUPPLEMENTARY NOTES
Environmental Management 13(1): 95-108
(Direct/Delayed Response Project)

16. ABSTRACT
The results of these surveys and the conclusions of the DDRP will be presented in several future papers. The current paper gives an overview of the context, rationale, logistical considerations, and implementation of these surveys, with special emphasis on the field activities of watershed mapping and soil sampling. This discussion should be useful to those planning, implementing, and managing survey activities in support of regional assessments of other environmental concerns, who are likely to face similar choices and constraints.

Key words: Acidic deposition; Soil surveys; Watersheds; Regional risk assessment; Eastern United States

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Release to Public	Unclassified	16
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE
SPRINGFIELD, VA. 22161

EPA/600/J-89/107

Watershed Surveys to Support an Assessment of the Regional Effects of Acidic Deposition on Surface Water Chemistry

JEFFREY LEE*†
ROBBINS CHURCH
United States Environmental Protection Agency
Environmental Research Laboratory
200 SW 35 St.
Corvallis, Oregon 97333, USA

DUANE LAMMERS†
LEON LIEGEL
United States Department of Agriculture Forest Service
Environmental Research Laboratory
200 SW 35 St.
Corvallis, Oregon 97333, USA

MARK JOHNSON†
DEBORAH COFFEY
RICHARD HOLDREN
NSI Technology Services Corporation
Environmental Research Laboratory
200 SW 35 St.
Corvallis, Oregon 97333, USA

DONALD STEVENS
Mathematics Department
Eastern Oregon State College
LaGrande, Oregon 97850, USA

ROBERT TURNER
Environmental Sciences Division
Oak Ridge National Laboratory
P.O. Box X
Oak Ridge, Tennessee 37830, USA

LOUIS BLUME
United States Environmental Protection Agency
Environmental Monitoring Systems Laboratory
P.O. Box 15027
Las Vegas, Nevada 89114, USA

ABSTRACT / Through the Direct/Delayed Response Project (DDRP), the United States Environmental Protection Agency is attempting to assess the risk to surface waters from acidic deposition in three regions of the eastern United States: the Northeast Region, the Southern Blue Ridge Province, and the Mid-Appalachian Region. The central policy question being addressed by the DDRP is: Within the regions of concern, how many surface water systems (lakes, streams) will become acidic due to current or altered levels of acidic sulfur deposition, and on what time scales?

The approach taken by the DDRP is to select a statistically representative set of watersheds in each region of concern and to project the future response of each watershed to various assumed levels of acidic deposition. The probability structure will then be used to extrapolate the watershed-specific results to each region. The data will be used also for statistical investigation of hypothesized relationships between current surface water chemistry and watershed characteristics.

Because the needed terrestrial data base was not available, regional watershed surveys were conducted to meet the specific data needs of the DDRP. Maps (1:24,000) of soils, vegetation, land use, depth to bedrock, and bedrock geology were made for each watershed. The soils were grouped into sampling classes based on their hypothesized response to acidic deposition. Randomized sampling of these classes provided regional means and variances of soil properties that can be applied to individual watersheds. Because of DDRP's need for consistency within and among regions, unique quality control/quality assurance activities were developed and implemented. After verification and validation, the DDRP data base will be made publicly available. This will be a unique and useful resource for others investigating watershed relationships on a regional scale.

The results of these surveys and the conclusions of the DDRP will be presented in several future papers. The current paper gives an overview of the context, rationale, logistical considerations, and implementation of these surveys, with special emphasis on the field activities of watershed mapping and soil sampling. This discussion should be useful to those planning, implementing, and managing survey activities in support of regional assessments of other environmental concerns, who are likely to face similar choices and constraints.

KEY WORDS: Acidic deposition; Soil surveys; Watersheds; Regional risk assessment; Eastern United States

*Author to whom correspondence should be addressed.
†Principal authors.

The potential effects of acidic deposition on surface waters (lakes, streams) is an important environmental issue throughout the industrialized world. The United

Environmental Management Vol. 13, No. 1, pp. 95–108

© 1989 Springer-Verlag New York Inc.

Figure 1. Regions included in the Direct/Delayed Response Project watershed surveys.

States Environmental Protection Agency (EPA) is attempting to assess the risk to surface waters in three regions of the eastern United States (Figure 1) through the Direct/Delayed Response Project (DDRP). This is being done for current and for possible future levels of acidic deposition. For example, industrial development without emission controls could lead to increased emissions and thus increased deposition; alternatively, emission controls could mean decreased emissions and thus decreased deposition.

The DDRP operates within the framework of a Congressionally mandated multiagency task force, the National Acid Precipitation Assessment Program (NAPAP). Principal collaborators within the DDRP are the EPA laboratories in Corvallis, Oregon, and in Las Vegas, Nevada, USA; several offices of the United States Department of Agriculture Soil Conservation Service (SCS; Table 1); and the Oak Ridge National Laboratory, Tennessee, USA. Many other institutions are also involved.

The central policy question being addressed by the DDRP is: *Within the regions of concern, how many surface water systems (lakes, streams) will become acidic due to current or altered levels of acidic sulfur deposition, and on what time scales?*

The specific objectives of the DDRP are summarized in Table 2. A detailed description of the underlying theory and approach of the DDRP is given by Church and Turner (1986).

Most of the lakes of concern have watershed-to-lake area ratios of 10 or greater (median ratio within the DDRP is 13:1; Landers and others 1988). Because of overhanging trees, streams on the small (i.e., <3000 ha) forested watersheds typical of the DDRP might not

Table 1. Soil Conservation Service offices involved in the DDRP watershed surveys

Office	Responsible personnel
Northeast state offices	
Connecticut, Rhode Island	E. Sautter, R. Shook
Massachusetts	G. Grice, S. Hundley
Maine	R. Babcock, R. Joslin, K. LaFlamme
New Hampshire	S. Pilgrim, H. Mount
New York	F. Gilbert, K. Wheeler, W. Hanna
Pennsylvania	G. Lipscomb, G. Martin
Vermont	D. Van Houten
Southern Blue Ridge Province state offices	
Georgia	T. Gerald, R. Wilkes
North Carolina	H. Smith, A. Goodwin
Tennessee	D. Newton, E. Lewis
Virginia	N. McLoda
Mid-Appalachian state offices	
Pennsylvania	G. Lipscomb, G. Martin
West Virginia	W. Hatfield, C. Loerch
National technical centers	
Northeast	O. Rice, T. Miller
South	L. Ratliff
National office	M. Meyer, K. Hinkley

have any water that is open to the sky (median ratio for watershed to stream surface within the DDRP is 41:1; Messer and others 1986). Thus, in most cases, over 90% of water reaching lakes and streams in the eastern United States has interacted with the vegetation, soil, bedrock, or other components of the watershed. In general, these interactions control the chemistry of the surface water in the eastern United States and determine whether it becomes acidic from acidic deposition (Altshuller and Linthurst 1984, Church and Turner 1986, National Academy of Sciences 1984, Shaffer and others 1988, Shaffer and Church, 1989). This may not be true for seepage lakes that receive most of their water directly from precipitation, for lakes with long retention times for which in-lake processes might control water chemistry, or for lakes or streams on highly disturbed watersheds. Lakes of the first two types are relatively few within the regions considered by the DDRP, however, and highly disturbed watersheds have been excluded.

Because the necessary terrestrial data base was not available, watershed surveys were conducted in each region to meet the specific data needs of the DDRP. Meeting DDRP's need for consistency within and among regions required developing unique quality control/quality assurance procedures. After verification and validation, the DDRP data base will be made publicly available. This will be a unique and useful resource for others investigating watershed relationships on a regional scale.

The results of these surveys and the conclusions of

Table 2. Objectives of the DDRP and some underlying scientific and policy questions

Objectives	Questions
1. Characterize the regional variability of soil and watershed characteristics	Do soils (e.g., phases, series, families) differ significantly in characteristics important for neutralizing acid inputs (e.g., sulfate adsorption capacity, percent base saturation)? Are the special interest watersheds representative of the regions of concern?
2. Determine which soil and watershed characteristics are most strongly related to surface water chemistry	Can lake chemistry be predicted from watershed and soil characteristics? Are the times required for surface waters to acidify correlated with particular kinds of soils?
3. Estimate the relative importance of key watershed processes across regions of concern	Are sulfate concentrations in most surface waters at steady state? To what extent is sulfate adsorption in soils at steady state? Is the supply of base cations generally adequate to neutralize acidic deposition for decades, even assuming very low or zero weathering rates?
4. Classify a sample of watersheds according to the times required for their surface waters to acidify, and extrapolate the results to the regions of concern	What watershed criteria are important in determining the time required for surface waters to acidify? How sensitive are methods of projection to the measurements of soil and other watershed characteristics? What is the frequency distribution of times required for surface waters to acidify?

the DDRP will be presented in several future articles. The current article gives an overview of the context, rationale, logistical considerations, and implementation of these surveys, with special emphasis on the field activities of watershed mapping and soil sampling. People who plan, implement, and manage survey activities in support of regional assessments of other environmental concerns are likely to face choices and constraints similar to those described in this paper.

Context of the Surveys

Because they were performed within the context of the DDRP, it is necessary to present an overview of the DDRP before describing the watershed surveys in detail. The sequence of major activities to be performed by the DDRP to meet the objectives given in Table 2 is summarized in Figure 2.

As a first step, the DDRP selected the Northeast, the Southern Blue Ridge Province, and the Mid-Appalachians as regions of concern (Figure 1). These were chosen because they receive high levels of acidic deposition, they contain surface waters thought to be potentially sensitive to acidic deposition, and the watersheds within them differ in characteristics thought to control sensitivity to acidic deposition.

After the regions were selected, a statistically representative set of watersheds within each region was selected from those included in the National Surface Water Survey (NSWS) (Landers and others 1988, Messer and others 1986, EPA 1985b), another EPA survey within NAPAP. The mapping phase of the DDRP watershed survey then provided information on the occurrence and extent of soils and other characteristics on these watersheds. Subsequently, the sampling phase provided soil descriptions and samples for the regional characterization of soil sampling classes developed specifically for this project.

The purpose of the watershed surveys was to provide the DDRP with data for three levels of analysis that are distinguished by increasing complexity. Level I analyses (system description) include statistical association of watershed characteristics with current or predicted surface water chemistry. Level II analyses (single-factor response time estimates) include estimates of the times required for individual or aggregated watershed characteristics (e.g., sulfate concentration in soil solution) to reach critical values. Level III analyses (dynamic systems modeling) use dynamic watershed simulation models to integrate key mechanisms controlling surface water response to acidic deposition. These models (Church and Turner 1986) provide predictions of the time required for surface waters to become acidic due to acidic deposition; this is done under various assumptions concerning future rates of acidic sulfur deposition.

Level II and Level III analyses each will provide estimates of the response times of individual watersheds. These will be extrapolated to the regions through the probability structure of the DDRP and the NSWS. The result will be a set of estimated frequency distributions of response times. For example, for the target population of lakes in the northeastern United

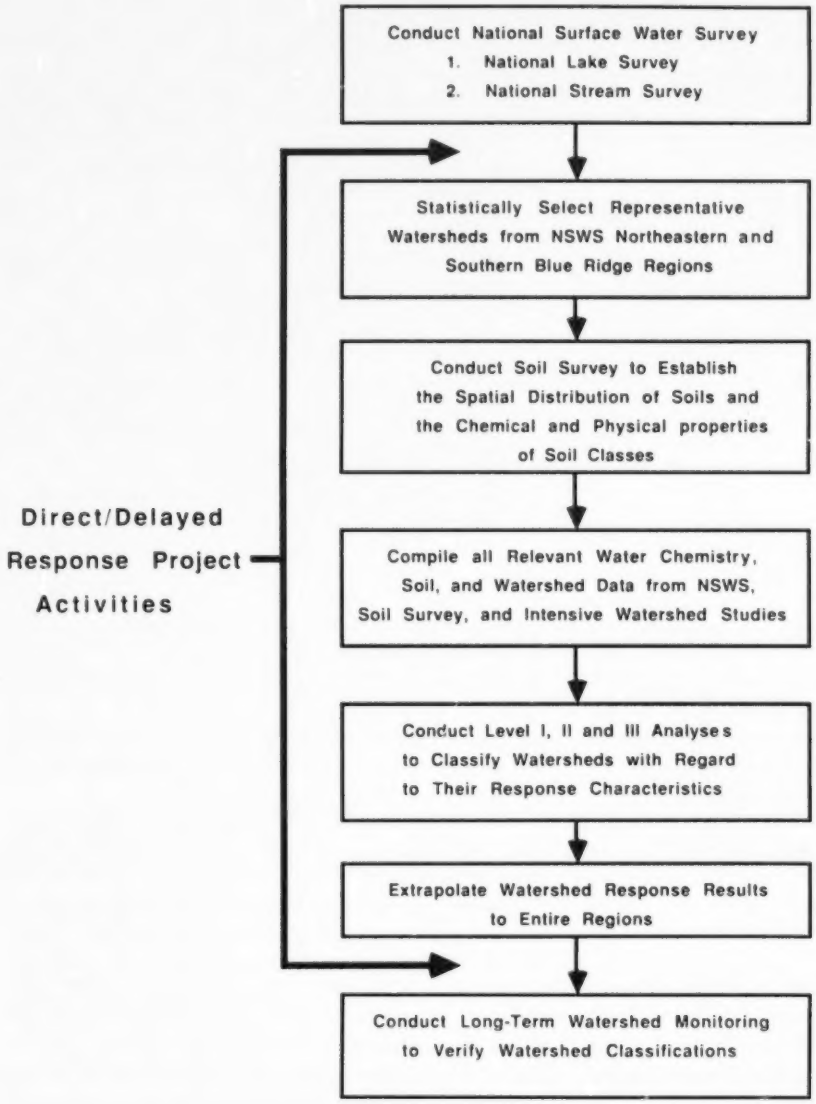
Conduct National Surface Water Survey
1. National Lake Survey
2. National Stream Survey
Statistically Select Representative Watersheds from NSWS Northeastern and Southern Blue Ridge Regions
Conduct Soil Survey to Establish the Spatial Distribution of Soils and the Chemical and Physical properties of Soil Classes
Direct/Delayed Response Project Activities
Compile all Relevant Water Chemistry, Soil, and Watershed Data from NSWS, Soil Survey, and Intensive Watershed Studies
Conduct Level I, II and III Analyses to Classify Watersheds with Regard to Their Response Characteristics
Extrapolate Watershed Response Results to Entire Regions
Conduct Long-Term Watershed Monitoring to Verify Watershed Classifications

Figure 2. Sequence of major activities associated with the Direct/Delayed Response Project.

States, it will be possible to estimate the number that will become acidic within a specified time period for current, reduced, or increased rates of acidic deposition.

DDRP survey activities started in the Northeast Region and then proceeded to the Southern Blue Ridge Province. The originally planned DDRP survey activities are complete for these regions, and the data are being analyzed. Survey activities for the Mid-Appalachian Region and mapping of additional watersheds in the Northeast Region are in progress.

Rationale for DDRP Watershed Surveys

Limitations of Existing Data

Originally, the DDRP considered using published soil maps and data on chemical, mineralogical, and physical characteristics of soils. The decision to include data collection as a significant component of the DDRP was made after a Pilot Soil Survey was conducted in the states of Maine, New York, and Virginia in the fall of 1984 (Reuss and Walthall 1987). As part

of the Pilot Soil Survey, the extent and usability of available soils data were assessed and found to be severely limited for the purposes of the DDRP.

One problem with the existing laboratory data is that they had been compiled over a long period of time by many laboratories. A variety of sampling methods and analytical techniques have been used instead of one standardized set of guidelines or protocols. This is an especially important consideration for soils, because many soil properties are defined operationally. Thus, if all relevant soil data for the three DDRP regions had been combined into a single data base, it would have lacked internal consistency. This is particularly a problem for older data.

One example of a limitation of published laboratory data is that certain soil properties important to the DDRP are not usually reported. For example, sulfate adsorption is thought to be a key soil process because it can control the mobility of sulfate and thus control the flow of acidity from the terrestrial to the aquatic system (National Academy of Sciences 1984, Church and Turner 1986). Sulfate adsorption characteristics, however, have been determined and reported for relatively few soils. Another example is cation-exchange capacity (CEC). Published data almost universally report buffered CEC. The models used in the DDRP, however, require unbuffered CEC, a property that is rarely reported.

The lack of readily available published soil survey reports is also a limitation. Many of the DDRP watersheds are in remote forested areas that are not currently covered by such reports. Soil surveys in these areas often are on small-scale maps or otherwise lack the resolution needed by DDRP. As was the case for the laboratory data, the soil surveys were made over an extended period, reflect what was known about the soils at the time, and are not always mutually consistent across counties, states, or regions. Although there are published state soil association maps (commonly at scales of 1:500,000 or 1:750,000) and regional soils maps, they do not provide sufficient resolution (i.e., on a small watershed scale) to meet DDRP objectives.

A further limitation of the available data is not directly related to soils. Surface water chemistry is influenced by watershed characteristics in addition to soil. For example, vegetation, bedrock geology, depth of permeable material, land use, and wetlands are all considered potentially important (Altshuller and Linthurst 1984, Church and Turner 1986, National Academy of Sciences 1984). Data on these watershed characteristics are generally less available than soil data.

Because of these limitations, DDRP scientists concluded that the only way to provide the project with the required data base was to conduct soil surveys designed specifically for this purpose. An important conclusion of the Pilot Soil Survey was that existing procedures for mapping, sampling, and analyzing soils could be adapted to meet the needs of DDRP. The soil surveys were broadened to include documentation of other relevant watershed characteristics, thus becoming watershed surveys.

Logistical Considerations for the Surveys

NAPAP is scheduled for completion in 1990. By that time, all available relevant data will have been used to support an assessment of the current and predicted effects of acidic deposition. This will include as much of the DDRP analyses as possible. This time constraint was the reason for proceeding with survey activities in new regions before the results for surveyed regions had been evaluated.

To fulfill its needs, DDRP tapped into an existing, highly developed infrastructure for mapping and sampling soils—the National Cooperative Soil Survey (NCSS). The DDRP surveys were implemented through the state offices of the United States Department of Agriculture Soil Conservation Service (SCS). This approach made good use of existing organizational structures. The large number of state offices involved, watersheds mapped and pedons sampled, and the large geographical area, however, raised concerns for regional consistency and logistics. These were addressed as described below.

Consistency and practicality of protocols. The protocols for mapping (Lammers and others 1987a,b) and sampling (Coffey and others 1987a,b) were developed from those used by the NCSS (Soil Survey Staff 1975, 1983, 1984). This was done cooperatively with those who would be responsible for implementing them, i.e., state office soils staff and other key participants (Table 1). This promoted mutual understanding of the rationale and intent of the specific protocols. Involvement of the people most knowledgeable of field conditions within the regions of concern enhanced the practicality of the protocols. An ancillary result of this approach will be that the data will be useful for the NCSS. Although this was not a goal of the DDRP survey, EPA recognized the opportunities for obtaining soil data and training field soil scientists in remote locations that, in many cases, were underrepresented or missing within the NCSS. The DDRP survey activities, therefore, were beneficial to both EPA and NCSS.

Consistent application of protocols. Before field activities (i.e., mapping and sampling) began, crews were trained at regional and state training workshops. Within each state, the state soil scientist was responsible for consistency. In some states, consistency was promoted by having all field personnel participate in field activities at the first site mapped or sampled within the state.

A key person in maintaining consistency in each region was the regional correlator/coordinator (RCC). This was an independent person with a strong practical knowledge of soil survey techniques within the region. The RCC visited field crews and provided guidance on application of the protocols. When necessary, the RCC consulted with the state soils staffs and the EPA task leader on problems in interpreting or applying the protocols. The RCC also performed other quality control/quality assurance duties (described below) and provided the EPA task leader with summary reports.

During field activities, the EPA task leader was responsible for tracking progress; facilitating resolution of procedural, administrative, or logistical problems; and maintaining communication. Thus, regional consistency was maintained by a constant dialogue among the state soils staffs, the RCC, and the EPA task leader. The latter was responsible for maintaining consistency among regions.

The above activities were designed to improve the quality of the survey products, and thus they come under the general heading of quality control. In contrast, quality assurance activities were designed to document the quality that was actually achieved in each region. These involved independent field evaluations, by persons not directly involved in survey activities, and exit meetings to document how protocols were interpreted, what problems the crews identified, and suggestions for improving quality or efficiency of operations. Quality assurance results from each region were used to improve procedures for subsequent regions.

Logistical support. To enhance regional consistency, standard supplies and equipment were provided to the field crews. During sampling, this was done through regional centers, i.e., the Soil Preparation Laboratories established in cooperation with Agriculture Experiment Stations (Table 3). When crews delivered soil samples to these laboratories, they were able to obtain needed supplies. Laboratory personnel inspected the samples for obvious problems (e.g., inadequate sample volume, poor labeling, possible contamination), providing an additional check on regional consistency.

The primary purpose of the preparation laboratories was to prepare soils for analysis by the analytical laboratories. This included inserting blind audit samples into each batch of samples submitted to the analytical laboratories. To promote consistency of soil preparation, it was desirable to have as few preparation laboratories as possible. Thus, it was necessary to balance consistency and logistical requirements in deciding the number and location of preparation laboratories.

Table 3. Soil preparation laboratories for the DDRP watershed survey

Laboratory	Responsible personnel
Northeast	
University of Connecticut	E. Levine, H. Luce
Cornell University	W. Waltman, R. Bryant
University of Maine	C. Spencer, I. Fernandez
University of Massachusetts	S. Bodine, P. Veneman
Southern Blue Ridge Province	
Clemson University	W. Smith, L. Norfleet
University of Tennessee	D. Litzke, M. Haren

Implementation of the DDRP Surveys

Selection of DDRP Watersheds

Watersheds included in the DDRP were selected from those previously sampled by two components of the National Surface Water Survey (NSWS): the Eastern Lake Survey (Landers and others 1988) and the National Stream Survey (Messer and others 1986, EPA 1985b). These two aquatic surveys provided chemical data of known high quality on surface waters that had been statistically selected within the regions, data that are essential to the DDRP. By selecting watersheds from the NSWS set, the statistical requirements of the DDRP were met efficiently.

Lakes in Northeast Region. In the Northeast Region, DDRP watersheds were selected from those included in region I of the Eastern Lake Survey. Phase I of the Eastern Lake Survey, conducted in the fall of 1984, was a synoptic chemical survey of over 1600 lakes in the eastern United States (768 in the Northeast). The population of lakes was defined as all lakes in the Northeast Region identifiable on US Geological Survey (USGS) 1:250,000 scale maps, which put a cartographic limit of approximately 4 ha on the minimum lake size. The probability sample was selected from this population. Some of the sample lakes were subsequently classified as nontarget lakes because they were dry, flowing water, too shallow, too small, ocean estuaries or embayments, or in an area of intense urban, industrial, or agricultural use (Landers and others 1988).

Preliminary data from the synoptic lake survey (phase I) were used to identify lakes of low interest, such as high acid-neutralizing capacity (ANC > 400 μeq/liter) lakes, shallow lakes (<1.5 m deep), or culturally disturbed lakes. These lakes were excluded from consideration as DDRP lakes. Very large lakes (surface area > 2000 ha) were placed in a reserved category and also excluded from sampling for the time being.

The DDRP required sample sizes of about 50 per stratum to maintain the required statistical precision. Logistical considerations limited the number of watersheds that could be adequately characterized to about 150. Thus, the Eastern Lake Survey phase I sample, minus large lakes and low interest lakes, had to be split into about three groups. The final division defined the three DDRP strata as: (1) ANC < 25 μeq/liter; (2) 25–100 μeq/liter; and (3) 100–400 μeq/liter. Selection of DDRP watersheds was coordinated with selection of lakes for the detailed sampling phase (phase II) of the Eastern Lake Survey. In each stratum, 60 lakes were selected using a systematic variable probability sampling scheme that resulted in approximately equal inclusion probabilities within strata. Thus, calculations of population statistics for a single stratum can be done without weighting individual data; weighting would only be needed to combine estimates across strata. After the sample was selected, lakes with large watersheds (>3000 ha) were dropped from the DDRP sample as impractical to map within the time and dollar constraints of the DDRP. The sample of 60 was randomly reduced to 50 for the phase II Eastern Lake Survey sample. Thus, most DDRP watersheds in the Northeast Region will also have phase II aquatic data.

Streams in Southern Blue Ridge Province and Mid-Appalachian Region. Watersheds in these regions were selected from those sampled by the National Stream Survey. The National Stream Survey defined *stream reach* as the length of a stream shown as a blue line on a USGS 1:250,000 map that lies between the downstream and upstream confluences with other blue line streams, or the upper end if no upper confluence was present. A rectangular grid of points, separated by a scaled distance of approximately 13 km (8 miles), was positioned at random over each 1:250,000 topographic map. The first stream reach intersected by a line from each point drawn downslope perpendicular to the contour lines was included.

All stream reaches selected in this way were used to establish physical characteristics of the stream reach population, e.g., distribution of reach lengths and drainage areas. In the National Stream Survey pilot study, stream reaches for chemical sampling were chosen by selecting reaches corresponding to every other grid point (Messer and others 1986). In the full National Stream Survey, a spatially clustered, randomized, systematic subsampling procedure was used to select reaches (EPA 1985b).

There were 51 reaches sampled in the pilot phase of the National Stream Survey (Messer and others 1986). Of these, only 35 had watersheds smaller than 3000 ha. All of these were included in the Southern Blue Ridge Province portion of the DDRP.

There were 127 stream reaches sampled by the National Stream Survey in its Mid-Atlantic Regions 2B and 2C (EPA 1985b). Of these, only 30 had watersheds smaller than 3000 ha, ANC at upper and lower nodes less than 200 μeq/liter, and no strong evidence of being affected by acid mine drainage; all of these were selected by the DDRP. Another seven watersheds were selected from the National Stream Survey Region 1D. These were close to either side of the line separating the Glaciated Allegheny Plateau and Catskill Mountains from the Northern Appalachian Ridges and Valley Major Land Resource Areas and were chosen because the line of glaciation has been hypothesized to divide regions differing in sensitivity to acidic deposition (Altshuller and Linthurst 1984, Church and Turner 1986, National Academy of Science 1984). Thus, a total of 37 watersheds were selected in the DDRP Mid-Appalachian region.

Special interest watersheds. In addition to the watersheds discussed above, six special interest watersheds (three in New York, two in North Carolina, and one in Virginia) were selected. These are watersheds for which long records of water quality exist. These data, in conjunction with soils and other watershed data obtained by the DDRP, will be used to calibrate the dynamic simulation models used in Level III analyses.

Mapping

Maps of the soils, vegetation, bedrock geology, and depth to bedrock were produced by the SCS field crews for each watershed. All maps were prepared on overlays of USGS topographic quadrangle maps or aerial photographs at a scale of 1:24,000 and were digitized for entry into a Geographic Information System. Minimum size of map delineations was 2.5–4.2 ha (6–10 acres) for all maps.

The total area mapped in the Northeast Region was approximately 75,000 ha (185,000 acres). In the Southern Blue Ridge Province the total area mapped was approximately 43,000 ha (102,000 acres). Mapping of approximately 39,000 ha (93,000 acres) in the Mid-Appalachian Region and of approximately

12,0000 ha (29,000 acres) on an additional 45 watersheds in the Northeast Region is currently in progress.

Products of mapping. The soils were mapped at an intensity (second order) approximating that of most county soil surveys (Soil Survey Staff 1983). To the extent possible, existing map legends were used to develop the regional legends. Map unit names and definitions were correlated across each region.

Vegetation cover types defined by the Society of American Foresters (Eyre 1980) were used to map the forest vegetation. These are perhaps somewhat broader than would be optimal for DDRP purposes; however, their advantages are that they have standard definitions and that nonforesters (i.e., soil scientists) can use them after a short training session.

Bedrock geology was obtained from currently available geology maps. Field crews noted obvious differences from the mapped geology, as well as geologic features of special interest.

A depth-to-bedrock map was made during soil mapping. Each delineation on the soil map was assigned to one of six depth classes, and the depth-to-bedrock overlay resulted from combining contiguous delineations of the same class. For soils deeper than 1.5 m, the mappers' knowledge of landscapes, road cuts, and stream incisements were used to estimate the depth to bedrock.

Quality control/quality assurance of mapping. The SCS state soils staff reviewed at least one watershed mapped by each survey party. A written progress field report was submitted to the RCC and EPA mapping task leader prior to completion of the mapping. Emphasis of the field review was on consistency and accuracy of the mapping and on conformance to protocols.

An integral part of each soil map unit description is a listing of the relative proportions of the soils, including inclusions, that make up the map unit (i.e., the soil components). This quantitative element was tested by examining soils at point locations along transects in the watersheds. By combining the results of many observations, a composite value for the ground truth of soil occurrence was obtained. This was done for map units on both a watershed basis and a regional basis. A quantitative evaluation of mapping quality was provided by statistically comparing these ground truths against the estimated composition contained in each map description. The approach of Arnold (1977, 1980) was used in the Northeast, and a modification of the approach of Steers and Hajek (1979) in the Southern Blue Ridge Province.

Except for a small number of transects done independently by the RCC, all transect observations were made by the mapping crews. About 12,000 point observations were made in the Northeast and 2000 in the Southern Blue Ridge Province. About 4000 point observations will be made in the Mid-Appalachian Region. These point observations constitute unique regional data sets on the composition of soil map units.

During mapping, the RCC controlled the mapping legend for the region, and participated in at least one field review in each state. After mapping was complete, the RCC conducted an independent evaluation of the mapping of randomly selected watersheds in each region. The latter included data for a quantitative evaluation of mapping quality from point observations on transects done independently by the RCC. The independent evaluation constituted the quality assurance activities for mapping, a step not usually taken in soil mapping.

Photo interpretation of land use. The selection criteria explicitly excluded watersheds that were heavily impacted by urban, industrial, or agricultural development. Nevertheless, land use and wetlands are thought to have influences on surface water chemistry that are possibly disproportionate to the area they occupy on watersheds. This might be especially true for areas near to the surface waters. A task complementary to mapping was implemented, therefore, to delineate and classify land uses and wetlands from interpretation of aerial photographs. Color infrared stereo aerial photographs (1:12,000 scale) of all DDRP watersheds in the Northeast were taken in spring of 1986, before the vegetation had leafed out. Nine major land-use categories were delineated to a resolution of 2.5 ha (6 acres); detailed wetland classes were interpreted to a resolution of 0.4 ha (1 acre) (Table 4). Point data on location of beaver lodges and dams (breached, unbreached) were also obtained. Overall accuracy and uniformity of these interpretations were determined by field and office quality assurance checks on a 10% subsample of watersheds by a second, independent contractor. Interpretation of aerial photographs taken of Mid-Appalachian watersheds is in progress.

Soil Sampling

Soils were described and sampled to provide the morphological, physical, and chemical data needed for the three DDRP levels of analysis. In the Northeast, 306 pedons were described and 2000 samples (i.e., about six horizons per pedon) were taken. (A pedon is the smallest volume of soil that has all the characteristics by which a specific soil is defined. Operationally, it is usually taken to be about a meter square in cross section to depth of 1.5 m or to bedrock, whichever is shallower.) The corresponding numbers for the Southern Blue Ridge Province are 110 pedons and

Table 4. Land use and wetland categories determined by interpretation of aerial photographs

Land-use categories	Wetland categories
Cropland	Aquatic bed
Forest land	Algal
Pasture land	Aquatic mos
Horticulture land	Rooted vascular
Waste disposal land (i.e., land fills)	Unknown submergent
	Unknown surface
Barren land	Emergent
Gravel or borrow pits	Broad-leaved deciduous
Urban land	Needle-leaved deciduous
Commercial	Broad-leaved evergreen
Industrial	Needle-leaved evergreen
Residential	Dead
Wetland	Deciduous
Cemeteries (point data)	Evergreen
	Open water/unknown
	Rocky bottom
	Rocky shore
	Scrub/shrub
	Broad-leaved deciduous
	Needle-leaved deciduous
	Broad-leaved evergreen
	Needle-leaved evergreen
	Dead
	Deciduous
	Evergreen

1000 samples. About 150 pedon descriptions and 1000 soil samples will be obtained in the Mid-Appalachian Region.

Soil sampling classes. In the Northeast, about 600 soils (mostly phases of soil series) were identified during mapping of 145 watersheds. In the Southern Blue Ridge Province, about 300 soils were identified on 35 watersheds. Because of the large number, it was impractical to sample each soil enough times to give statistically adequate estimates of the means and variances of the relevant soil properties.

A more efficient procedure was to combine the identified soils into a tractable number of groups, or sampling classes, that were either known or expected to have similar chemical and physical characteristics with respect to their response to acidic deposition. Each of these classes was sampled across several watersheds, so that the means and variances of the characteristics of each class can be computed for the region. These regional means and variances can then be used to build area- or volume-weighted estimates, with estimates of error, of each watershed's characteristics. This can be done also for specific portions of watersheds, e.g., poorly drained soils near lakes. Note that, in this approach, a given soil sample does not represent the specific watershed from which it came. Instead, it contributes to a set of samples which, collectively, represent a specific sampling class on all DDRP watersheds within the region for which the sampling class is defined. Because the DDRP will estimate the uncertainties of its projections and conclusions, it is necessary to know the variability of a given characteristic for a sampling class within a region, not just the value associated with the central concept of the class.

The sampling classes were developed at workshops by the soil scientists most familiar with the soils occurring on the DDRP watersheds, in cooperation with the statisticians and modelers who would be using the data (EPA 1985a). Through this discussion, the soil scientists were able to identify soil properties that were important in themselves or were proxies for important properties. Different schemes for defining sampling classes were developed for use by the DDRP in the Northeast (Figure 3) and in the Southern Blue Ridge Province (Figure 4). Sampling classes for the Mid-Appalachian Region will be developed after mapping is complete.

Each scheme is largely dependent on parent material, water movement (e.g., drainage, particle size, soil depth), organic content, and base status. Where taxonomic classification was used to differentiate classes, these properties are implicit in the classification. These diagrams (Figures 3 and 4) were designed to be used by the field crews as keys to assign any soil encountered on any DDRP watershed to a sampling class. Thus, during sampling, these diagrams helped standardize soil concepts within regions.

The sampling classes represent complex hypotheses for grouping soils by response to acidic deposition. As part of the DDRP analyses, soil descriptions and laboratory data will be used to explore the validity of these hypotheses. The main purpose of the classes, however, was to increase the statistical efficiency of the soil sampling design. If, for example, one pedon had been sampled for every 40 ha (larger than some DDRP watersheds), a total of 1850 pedons would have been required in the Northeast Region. Preliminary analysis suggests that the 306 pedons actually sampled in the Northeast Region were adequate for DDRP objectives. Final judgement on this will not, however, be possible before the DDRP analyses are complete.

Selection of sampling sites. There is a strong tendency for soil scientists to select typical soils for sampling. Although this is proper for most applications, it would not have been appropriate for the statistically based sampling scheme used by the DDRP. To ensure an unbiased sample for estimating means and variances of the characteristics of sampling classes over the regions, the DDRP used a unique scheme of random selection of sampling sites for each sampling class. This scheme had three major parts: (1) random selection of watersheds from those on which the desired sampling class

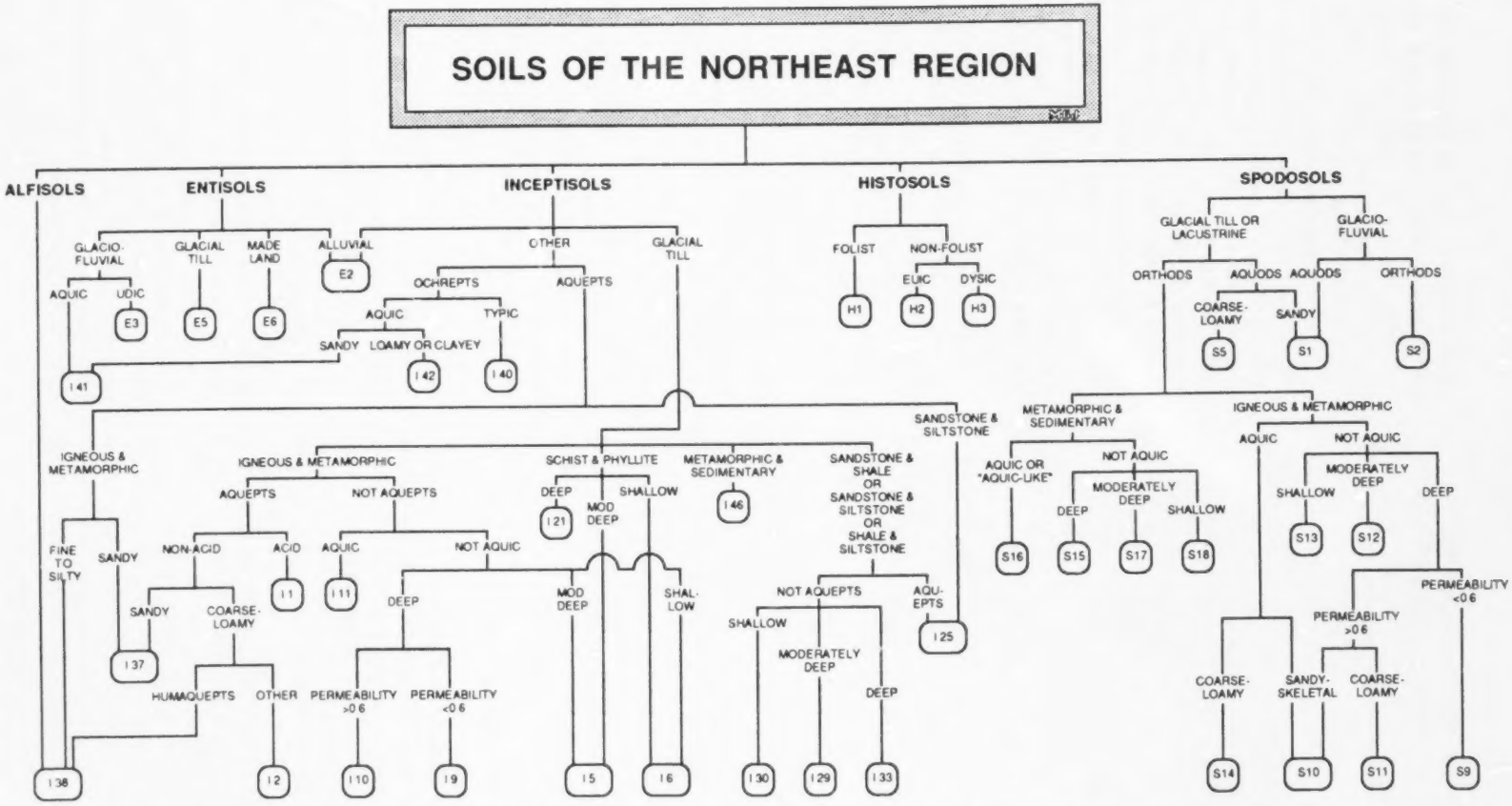

Figure 3. Flowchart defining soil sampling classes for assessing the potential effects of acidic deposition in the northeastern United States.

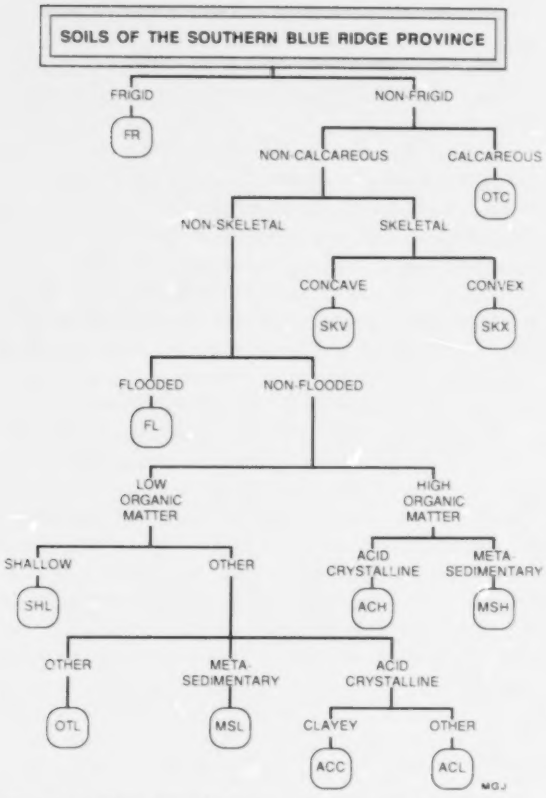

Figure 4. Flowchart defining soil sampling classes for assessing the potential effects of acidic deposition in the Southern Blue Ridge Province.

occurs; (2) random selection of predetermined sampling sites on soils maps within delineations in which the class occurs; and (3) random selection of transect direction if the field crew found that the desired sampling class did not occur within 5 m of the preselected site.

For most of the soil scientists involved, the random approach to selecting sampling sites was novel and arduous. Because the need for regional estimates of means and variances was understood, the approach was accepted. Some soil scientists found that this approach expanded their concepts and understanding of soils by requiring them to look in detail at soils in atypical locations. The random approach did not at all diminish the need for considerable knowledge and skill on the part of the field soil scientist, but in fact relied on this knowledge and skill in identifying soils.

Quality control/quality assurance of sampling. The purpose of the quality control/quality assurance tasks for sampling was to ensure and document that the samples were collected and handled in a consistent, proper manner and that the chain of custody for each sample was properly documented.

During sampling, every crew was audited by the state soils staff and the RCC, who were responsible for consistency within each state and within each region, respectively. At least one site per state was audited jointly by the state soil staff and the RCC.

The quality control activities also provided unique information on the variability of pedon descriptions prepared by different soil scientists. The state soil staff and RCC each performed independent descriptions of pedons that had also been described by the sampling crews. Thus, for some pedons, up to three independent descriptions were available. The primary purpose was not to decide which soil scientist was "right," but to document the variability inherent in a procedure that is somewhat subjective. Comparison of descriptions was also useful to promote consistent application of soils concepts within states and regions.

Each crew was also audited by a member of the EPA quality assurance staff. The EPA auditor used a detailed checklist to document adherence or deviation from protocols as given in the DDRP sampling manuals. This was an independent evaluation, fulfilling the quality assurance needs.

DDRP Watershed Survey Data Base

The DDRP watershed data base has four major components linked together in a SAS data base. The first contains all mapped information collected during the surveys, including digitized versions of all maps and overlays. The second component contains the pedon descriptions, recorded by the sampling crews on a draft soil description form (draft Soils-232) with codes designed for later computer entry. The third component contains the results of a number of chemical and physical laboratory analyses (Table 5) performed on soil samples collected during the soil surveys (Bartz and others 1987, Cappo and others 1987).

The last component contains the mineralogical analyses (Table 5) done to determine the dominant minerals in the soils of the two regions. These data will be used to assess and determine the rates of mineral weathering, which is the ultimate source of base cations.

As with all aspects of the DDRP surveys, data entry and management were subjected to rigorous quality control/quality assurance procedures: visual scanning of the data reporting forms, double entry of data, resolution and documentation of discrepancies, and verification/validation of data. The data management system maintains a documentation trail to ensure the

Table 5. Laboratory analyses of DDRP soil samples

Chemical analyses
1. pH (distilled water; 0.01 M $CaCl_2$; 0.002 N $CaCl_2$)
2. Total carbon[a]
3. Total nitrogen
4. Total sulfur
5. Cation exchange capacity
   a. 1 N NH_4OAc, pH = 7.0
   b. 1 N NH_4Cl, unbuffered
6. Exchangeable bases (Na, K, Mg, Ca)
   a. extraction by 1 N NH_4OAc, pH = 7.0
   b. extraction by 1 N NH_4Cl, unbuffered
7. Exchangeable acidity
   a. $BaCl_2$—TEA method, pH = 8.2
   b. 1 N KCl—total acidity, exchangeable Al
8. Extractable iron and aluminum
   a. sodium pyrophosphate
   b. ammonium oxalate
   c. citrate-dithionate
9. Extractable sulfate
   a. water soluble
   b. phosphate extractable
10. Sulfate adsorption isotherms (six points)
11. Specific area

Physical analyses
1. Particle size
2. Bulk density

Mineralogical analyses
1. X-ray diffraction
2. Thin sections
3. Scanning electron microscopy/energy dispersive XRF

[a]A qualitative test for inorganic carbon is also performed. In the two completed regions, only two samples tested positive.

traceability and completeness of the data base. These procedures and the data base contents are discussed more completely in the DDRP support documents (Jones and others 1986, Schmoyer and others 1987, Turner and others 1987). After the data are validated, this data base will be made publicly available.

Summary

The DDRP was implemented by EPA to estimate the number of lakes and streams in the eastern United States that might become acidic due to current or altered levels of acidic deposition, and the time scales on which this might occur. This is being done under NAPAP, a Congressionally mandated interagency task force scheduled for completion in 1990. Some DDRP analyses will occur after this date.

The approach taken by the DDRP is to select a statistically representative set of watersheds in each region of concern and to project the future response of each watershed to various assumed levels of acidic deposition. The probability structure will then be used to extrapolate the watershed-specific results to each region. The statistical framework is being used also for statistical investigation of hypothesized relationships between current surface water chemistry and watershed characteristics.

Because the needed terrestrial data base was not available, regional watershed surveys were conducted to meet the specific data needs of the DDRP. Maps (1:24,000) of soils, vegetation, land use, depth to bedrock, and bedrock geology were made for each watershed. The soils were grouped into sampling classes based on their hypothesized response to acidic deposition. Randomized sampling of these classes provided unbiased regional means and variances of soil properties that can be applied to individual watersheds.

Because of DDRP's need for consistency within and among regions, unique quality control/quality assurance activities were developed and implemented. These included development, control, and correlation of regional map legends; regional training workshops for mapping and sampling; extensive use of point observations on transects to refine regional estimates of soil map unit composition; a RCC responsible for maintaining regional consistency of procedures; independent descriptions of pedons by two or three persons; independent evaluation of products (quality assurance); exit meetings with field crews to document interpretation of protocols, problems encountered, and suggestions for improvement of operations; and submission of blind audit samples to analytical laboratories.

Detailed evaluations of mapping and sampling are given by Lammers and others (1987a,b) and Coffey and others (1987a,b) for each of the two regions that have been completed. Preparation laboratory activities were evaluated by Papp (1987) and by Haren and Van Remortel (1987). Overall, survey activities went as planned. The desired maps and soil samples were obtained within the time and resource constraints of the project. The statistical approach and the field activities have undergone several peer reviews successfully. The surveys have received a Merit Award from the Soil and Water Conservation Society, and a statement of support from the National Association of Conservation Districts.

Operational refinements suggested from quality assurance evaluations include auditing field activities soon after they start, using standard formats for documenting crew and auditor activities, and improving coordination between field crews and support facilities. These changes, along with some improvements in equipment, are being included in Mid-Appalachian survey activities.

Preliminary analysis indicates that the DDRP watershed surveys have met the data requirements of the DDRP. Final judgement of this will not, however, be possible before the DDRP analyses are complete. Nevertheless, it is clear that the DDRP watershed surveys have developed an extensive, internally consistent, statistically based data base on soils and other watershed properties. Thus, the DDRP surveys can serve as prototypes for designing and implementing terrestrial surveys in support of the regional assessment of other environmental concerns.

Acknowledgments

The authorship of this article reflects only a few of the many people who have had significant roles in the DDRP Watershed Surveys. A more complete list is given below.

The RCC for the Northeast was John Warner, former SCS Assistant State Soil Scientist for New York; he also is the RCC for the Mid-Appalachians. In the Southern Blue Ridge Province, the RCC was Hubert Byrd, former State Soil Scientist for North Carolina.

Watershed and site selection: R. Church, D. Stevens, K. Thornton, D. Marmorek, S. Overton, J. Baker, J. Blick, B. Rochelle.

Management and operations: J. Lee, D. Lammers, R. Church, state soils staffs (Table 1), M. Papp, preparation laboratory staffs (Table 3), R. Turner, L. Liegel, R. Holdren, J. Goyert, K. Van Hoesen, C. Brandt.

Quality assurance: D. Coffey, H. Byrd, J. Warner, D. Cassell, L. Blume, K. Cappo, P. Arberg, J. Bartz, P. Shaffer, C. Palmer, D. Schmoyer.

Other contributors: S. Buol, J. Ferwerda, L. Ratliff, O. Rice, T. Miller, M. Mausbach, M. Meyer, B. Hajek, R. Arnold, J. Reuss, M. David, F. Kaisaki.

In addition to the above, more than 100 soil scientists were involved in mapping and sampling; numerous others were involved in the DDRP activities not covered in this article.

Oak Ridge National Laboratory is operated for the US Department of Energy by Martin Marietta Energy Systems Inc. under contract number DE-AC05-840R214000.

Finally, the authors wish to thank the following people who reviewed a draft of this paper: J. Eilers, H. Huddleston, P. Kaufmann, M. Meyer, C. Powers, K. Randolph, and L. Ratliff.

Literature Cited

Altshuller, A. P., and R. A. Linthurst. 1984. The acidic deposition phenomenon and its effects: Critical assessment review papers. EPA-600/8-83-016AF. US Environmental Protection Agency, Office of Research and Development, Washington, DC.

Arnold, R. W. 1977. Clean brush approach achieves better concepts in soil survey. Quality conference proceedings. Bergams, New York. pp. 61–92. Department of Soils, Cornell University, Ithaca, New York.

Arnold, R. W. 1980. Graphical solution of binomial confidence limits in soil survey. Northeastern Soil Survey Work Planning Conference Report. US Department of Agriculture—Soil Conservation Service, National Technical Service Center, Chester, Pennsylvania.

Bartz, J. K., S. K. Drousé, K. A. Cappo, M. L. Papp, G. A. Raab, L. J. Blume, M. A. Stapanian, F. C. Garner, and D. S. Coffey. 1987. Direct/Delayed Response Project: Quality assurance plan for soil sampling, preparation and analysis. EPA/600/8-87/0231. US Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Las Vegas, Nevada.

Cappo, K. A., L. J. Blume, G. A. Raab, J. K. Bartz, and J. L. Engels. 1987. Analytical methods manual for the Direct/Delayed Response Project soil survey. EPA 600/8-87/020. US Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Las Vegas, Nevada.

Church, M. R., and R. S. Turner (eds.). 1986. Factors affecting the long-term response of surface waters to acidic deposition: State of the science. EPA 600/3-86-025. US Environmental Protection Agency, Corvallis, Oregon. NTIS PB86-178-118AS.

Coffey, D. S., J. J. Lee, D. A. Lammers, M. G. Johnson, and G. R. Holdren. 1987a. Direct/Delayed Response Project Northeast field sampling report, Vol. I, Field sampling. EPA/600/4–87/030. US Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Las Vegas, Nevada.

Coffey, D. S., J. J. Lee, J. K. Bartz, R. D. Van Remortel, M. L. Papp, and G. R. Holdren. 1987b. Direct/Delayed Response Project: Field operations and quality assurance report for soil sampling in the Southern Blue Ridge Province of the United States, Vol. I, Sampling. EPA 600/4-87/041. US Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Las Vegas, Nevada.

EPA (Environmental Protection Agency). 1985a. Direct/Delayed Response Project: Definition of soil sampling classes and selection of sampling sites for the Northeast. US EPA, Environmental Research Laboratory, Corvallis, Oregon.

EPA (Environmental Protection Agency). 1985b. National surface water survey: National stream survey mid-Atlantic phase I and southern screening research plan. US EPA, Office of Research and Development, Washington, DC.

Eyre, F. H. 1980. Forest cover types of the United States and Canada. Society of American Foresters, Washington, DC.

Haren, M. F., and R. D. Van Remortel. 1987. Direct/Delayed Response Project: Field operations and quality assurance report for soil sampling and preparation in the Southern Blue Ridge Province of the United States, Vol. II, Preparation. EPA/4-87/041. US Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Las Vegas, Nevada.

Jones, K. E., G. K. Morris, C. R. Myers, B. T. Rhyne, and J. A. Watts. 1986. User's guide for the soil description program: Southern Blue Ridge Province soil sampling survey. Oak Ridge National Laboratory, Computing and Telecommunications Division, Oak Ridge, Tennessee.

Lammers, D. A., D. L. Cassell, J. J. Lee, D. L. Stevens, R. S. Turner, W. G. Campbell, and M. G. Johnson. 1987a. Field operations and quality assurance/quality control for Direct/Delayed Response Project soil mapping activities in the Northeast region. US Environmental Protection Agency, Environmental Research Laboratory, Corvallis, Oregon.

Lammers, D. A., D. L. Cassell, J. J. Lee, D. L. Stevens, W. G. Campbell, and M. G. Johnson. 1987b. Field operations and quality assurance/quality control for Direct/Delayed Response Project soil mapping activities in the Southern Blue Ridge Province. US Environmental Protection Agency, Environmental Research Laboratory, Corvallis, Oregon.

Landers, D. H., W. S. Overton, R. A. Linthurst, and D. A. Brakke. 1988. Eastern lake survey: Regional estimates of lake chemistry. *Environmental Science and Technology* 22:128–135.

Messer, J. J., K. N. Eshleman, S. M. Stambaugh, and P. R. Kaufmann. 1986. National Surface Water Survey: National Stream Survey phase I—pilot survey. EPA/600/4-86/026. US Environmental Protection Agency, Washington, DC.

National Academy of Sciences. 1984. Acid deposition: Processes of lake acidification. National Academy Press, Washington, DC.

Papp, M. L. 1987. Direct/Delayed Response project: Field operations and quality assurance report for soil sampling and preparation in the northeastern United States, Vol. II, Sample preparation. US Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Las Vegas, Nevada.

Reuss, J. O., and P. M. Walthall. 1987. Final report on interpretation of US EPA pilot soil survey. US Environmental Protection Agency, Environmental Research Laboratory, Corvallis, Oregon.

Schmoyer, D. D., G. J. Morris, A. E. Osborne-Lee, J. A. Watts, J. C. Goyert, and R. S. Turner. 1987. Users' guide for the soil chemistry system. Oak Ridge National Laboratory, Computing and Telecommunications Division, Oak Ridge, Tennessee.

Shaffer, P. W., and M. R. Church. 1989. Terrestrial and in-lake contributions to the alkalinity budgets of drainage lakes: An assessment of regional differences. *Canadian Journal of Fisheries and Aquatic Science* (in press).

Shaffer, P. W., R. P. Hooper, K. L. Eshleman, and M. R. Church. 1988. Watershed vs in-lake alkalinity generation: A comparison of rates using input–output studies. *Water, Air and Soil Pollution* vol. 39 (in press).

Soil Survey Staff. 1975. Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. US Department of Agriculture–Soil Conservation Service, Agriculture Handbook 436, US Government Printing Office, Washington, DC.

Soil Survey Staff. 1983. National soils handbook. US Department of Agriculture–Soil Conservation Service, Agriculture Handbook 430, US Government Printing Office Washington, DC.

Soil Survey Staff. 1984. Procedures for collecting soil samples and methods of analysis for soil survey. US Department of Agriculture–Soil Conservation Service, SSIR 1, US Government Printing Office, Washington, DC.

Steers, C. A., and B. F. Hajek. 1979. Determination of map unit composition by a random selection of transects. *Soil Science Society of America Journal* 43:156–160.

Turner, R. S., C. C. Brandt, D. D. Schmoyer, J. C. Goyert, K. D. Van Hoesen, G. R. Holdren, M. L. Papp, and J. A. Watts. 1987. Direct/Delayed Response Project: Guide to using and interpreting the data base. ORNL/TM-10369. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This article documents research that was conducted under the auspices of the U.S. Environmental Protection Agency (USEPA). As an arm of the government, the USEPA has a paid up, non-exclusive, irrevocable, worldwide license to reproduce, prepare derivative works, and distribute to the public all of the material contained herein, and to grant others acting on its behalf the right to do so. The USEPA grants to the National Technical Information Service, Department of Commerce, the right to act as its agent in the distribution of this material.